



National Aeronautics and Space Administration

The Impact of Suggestive Maneuver Guidance on Pilots Performing the Detect and Avoid Function

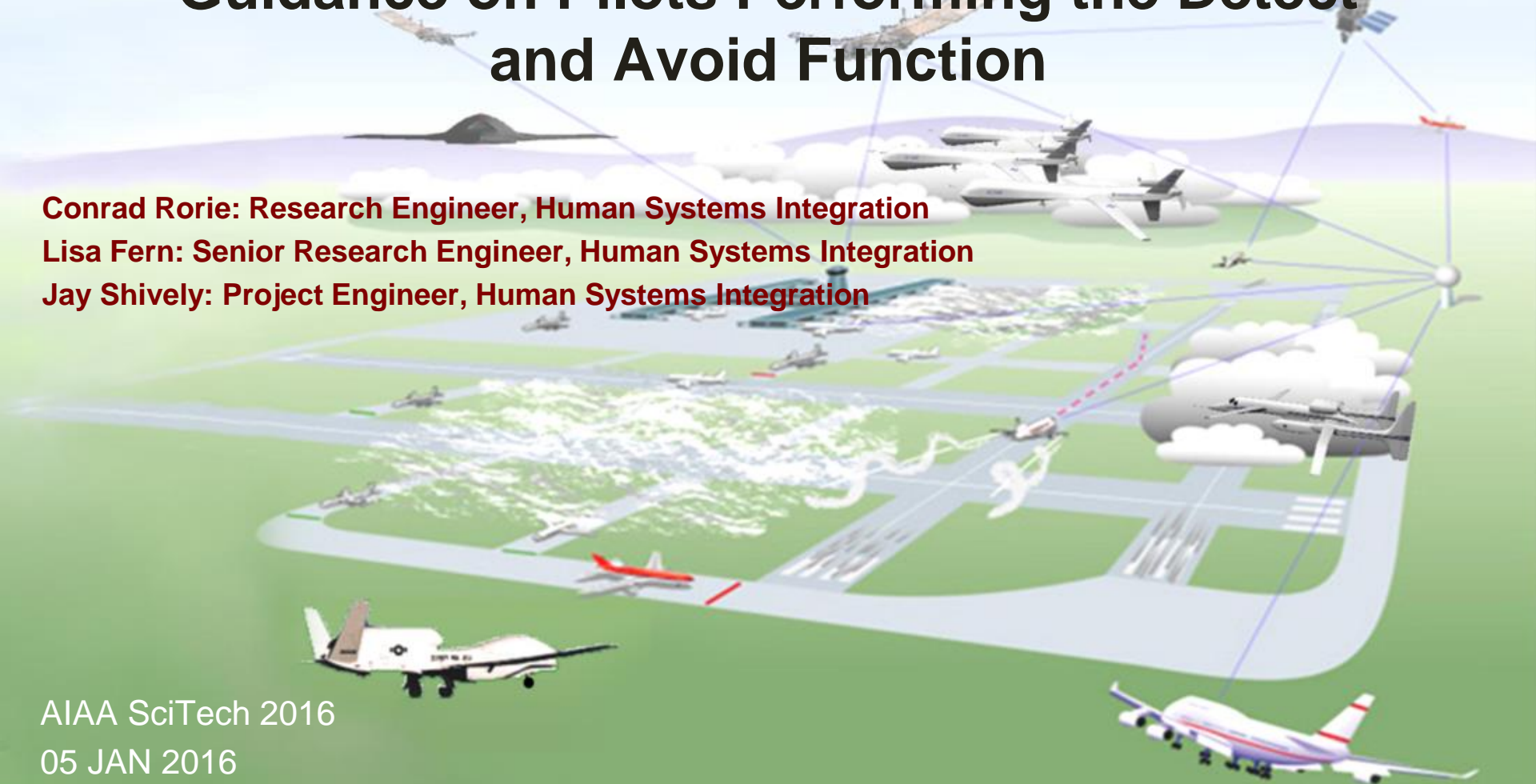
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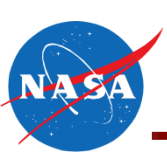
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AIAA SciTech 2016

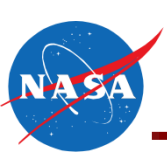
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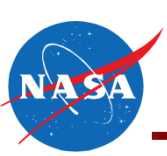
PT5 Background

- Motivation
 - Build upon previous human-in-the-loop simulations results and lessons learned to identify minimum DAA display and guidance requirements for draft SC228 MOPS
 - PT4
 - A suite of integrated guidance tools led to faster pilot responses, fewer losses of well clear and less severe losses of well clear when they did occur
 - iHITL
 - Integrated guidance tools led to less severe losses of well clear and faster pilot responses than seen in PT4
 - AFRL Maneuver Study
 - Guidance (in the form of 'banding') led to faster pilots responses and fewer collision avoidance alerts



PT5 Background

- Modifications from previous sims:
 - Guidance tools were no longer tightly coupled to the ground control station's auto pilot interface
 - Removed advanced features present in iHITL (e.g., well clear ring & dead reckoning lines)
 - Modeled sensor uncertainty for the first time
 - Critical to test displays and algorithms with 'imperfect' data prior to flight tests
 - Implemented alerting structure as part of the draft MOPS
 - Increased workload on the pilot
 - More secondary tasks and interaction with their route

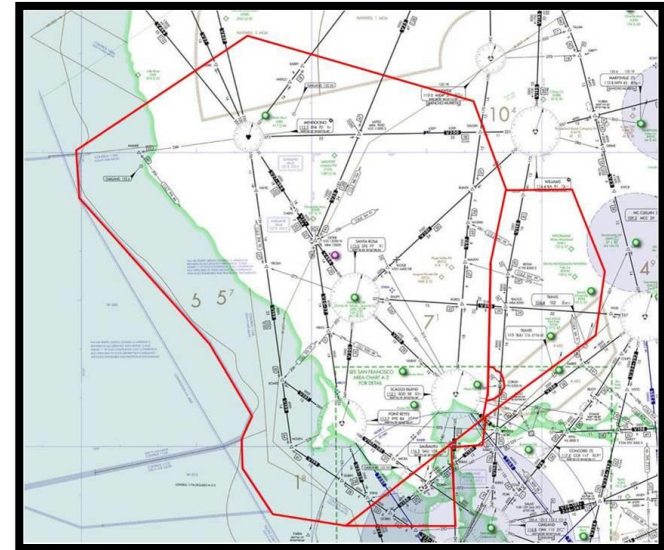


Experimental Design

- Mixed Factorial Design
 - *Display Configuration* (Within-Subjects Independent Variable):
 - **Configuration 1:** Minimum Information Set (No Guidance)
 - **Configuration 2:** Stratway+ No Fly Bands
 - **Configuration 3:** JADEM Omni Bands
 - **Configuration 4:** JADEM Vector Planning Tools

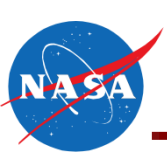
- Participants

- 16 active UAS pilots
 - Avg. 37 years old (all male)
 - Manned Flying Experience
 - Civil airspace: 575 avg. hrs
 - Military: 1760 avg. hrs
 - Unmanned Flying Experience
 - Civil airspace: 30 avg. hrs
 - Military: 1100 avg. hrs



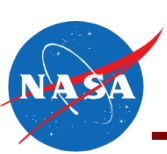
- Task

- Fly simulated MQ-9 through Class E airspace (Oakland Center – ZOA 40/41)
 - Navigate along pre-filed routes (used AFRL's Vigilant Spirit Control Station)
 - Maintain well clear from pre-scripted conflicts
 - Coordinate with ATC
 - Attend to secondary tasks (e.g., chat messages, system alerts)



Experimental Design

- Pre-planned conflicts with ownship
 - 6 scripted encounters predicted to lose well clear
 - 3 with cooperative traffic (detected at max range of 15nm)
 - 3 with non-cooperative traffic (detected at max range of 8nm, with limited FoR)
 - 3 scripted encounters predicted to become preventive self separation alerts

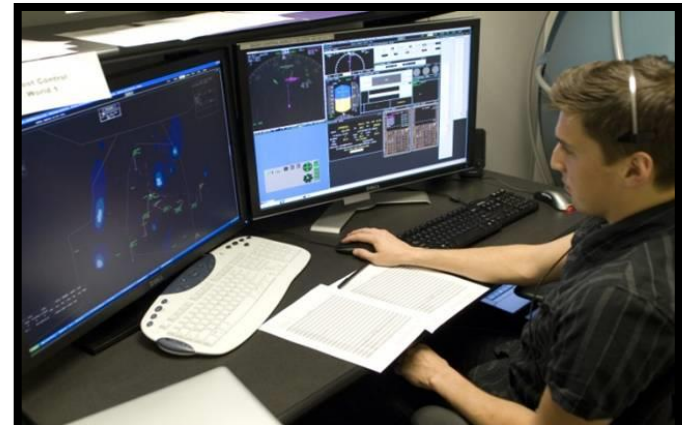


Experimental Design

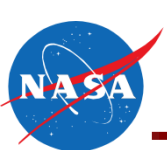
- Simulation confederates
 - NATCA controller managed UAS and manned traffic within ZOA 40/41
 - Simulated manned traffic based on actual sector activity
 - Pseudo-pilots managed all manned traffic to provide dynamic sector activity
 - ATC SME operated as 'ghost' controller to ensure conflicts were generated








Air Traffic Control Station (MACS)

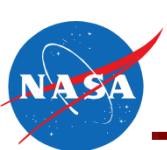


Pseudo Pilot Station



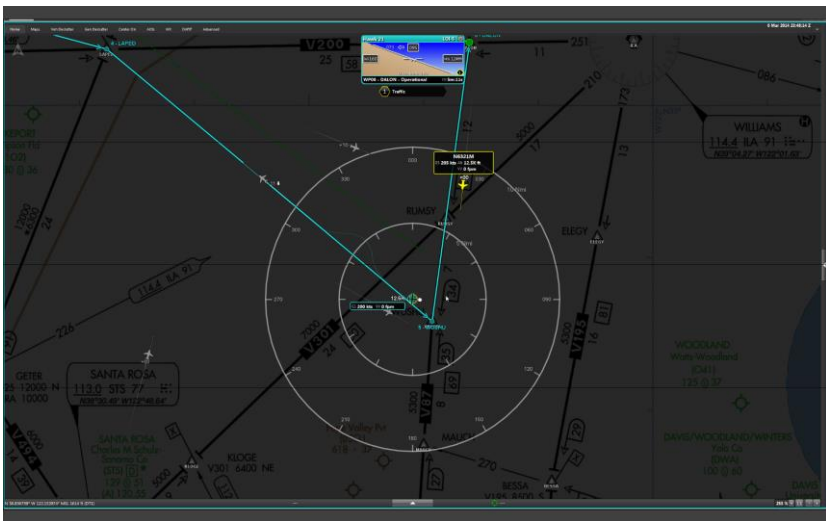
Draft MOPS Alerting Structure

Symbol	Name	Pilot Action	Buffered Well Clear Criteria	Time to Loss of Well Clear	Aural Alert Verbiage
	Self Separation Warning Alert	<ul style="list-style-type: none"> Immediate action required Notify ATC as soon as practicable after taking action 	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	25 sec (TCPA approximate: 60 sec)	"Traffic, Maneuver Now"
	Corrective Self Separation Alert	<ul style="list-style-type: none"> On current course, corrective action required Coordinate with ATC to determine an appropriate maneuver 	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	75 sec (TCPA approximate: 110 sec)	"Traffic, Separate"
	Preventive Self Separation Alert	<ul style="list-style-type: none"> On current course, corrective action should not be required Monitor for intruder course changes Talk with ATC if desired 	DMOD = 0.75 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	75 sec (TCPA approximate: 110 sec)	"Traffic, Monitor"
	Self Separation Proximate Alert	<ul style="list-style-type: none"> Monitor target for potential increase in threat level 	DMOD = 0.75 nmi HMD = 1.5 nmi ZTHR = 1200 ft modTau = 35s	85 sec (TCPA approximate: 120 sec)	N/A
	None (Target)	<ul style="list-style-type: none"> No action expected 	Within surveillance field of regard	X	N/A

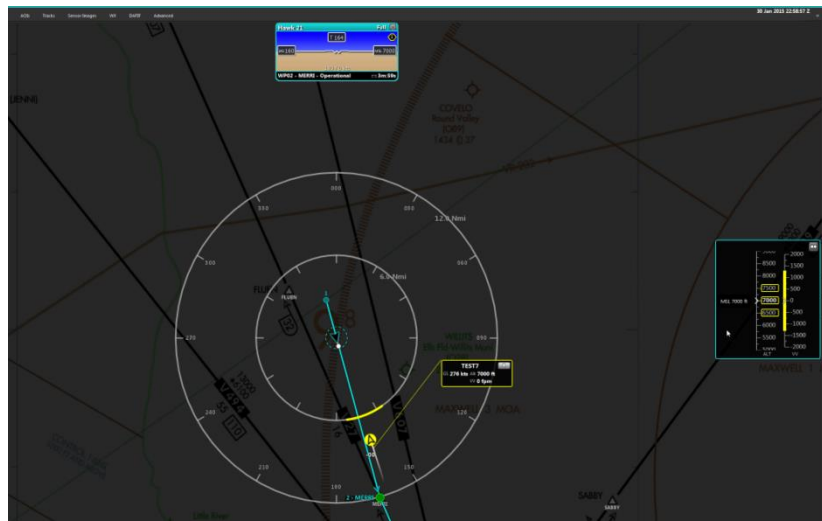


Display Conditions

D1



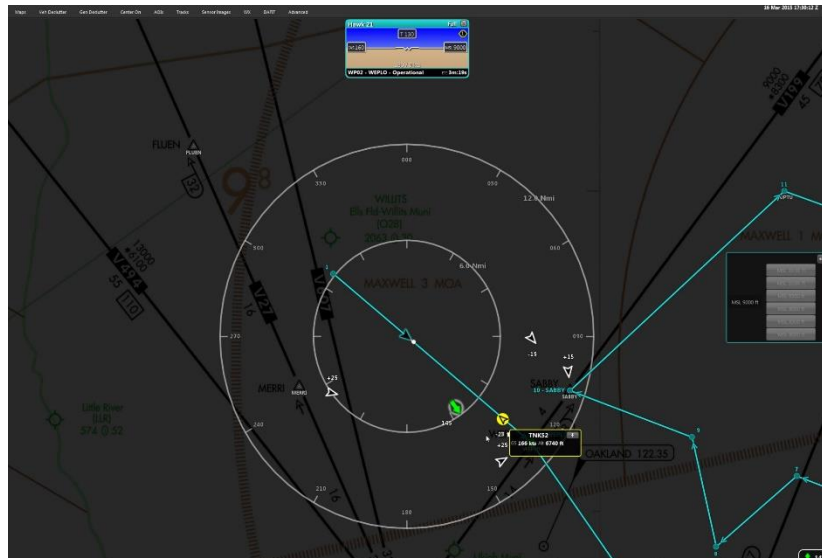
D2

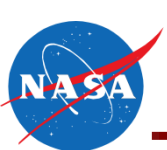


D3



D4





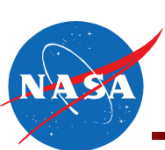
Display Conditions



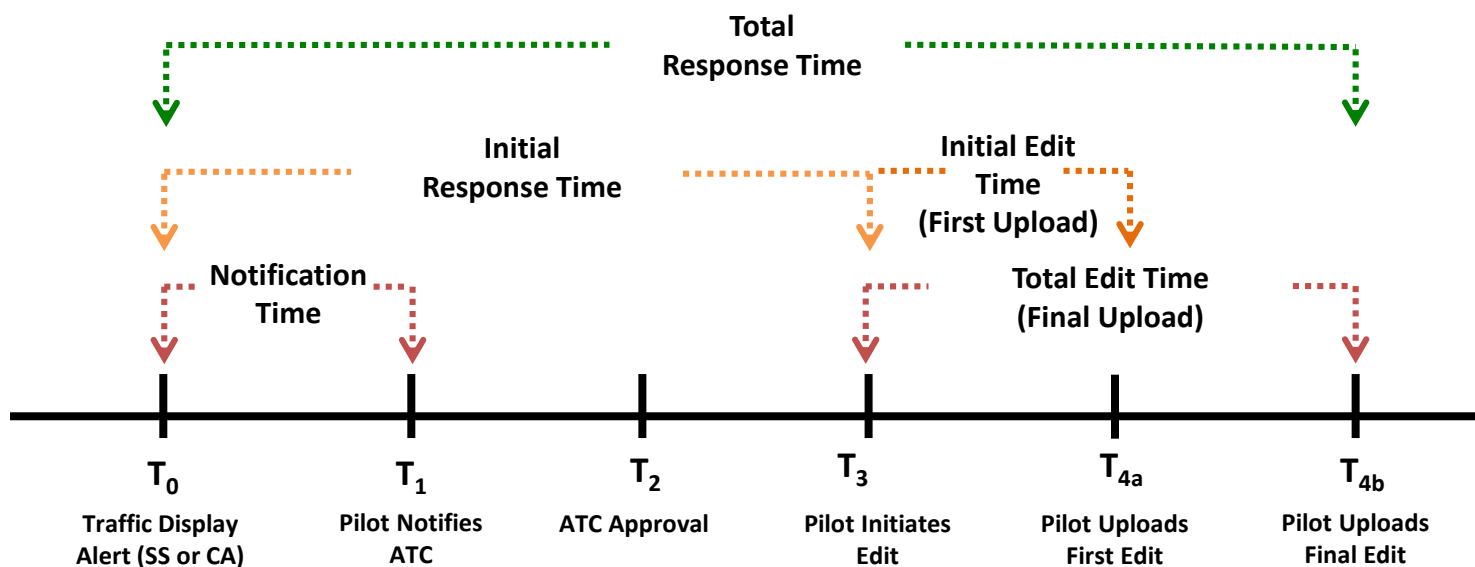


Encounter Statistics

- Total Number of Encounters:
 - 282 encounters analyzed in following measured response data
 - 37 (13%) encounters were excluded due to pilot maneuvering prior to receiving an alert
- By Threat Level
 - 244 Corrective SS Alerts issued
 - 111 SS Warning Alerts issued
- By Intruder Equipage
 - 138 encounters with Cooperative Traffic
 - 144 encounters with Non-Cooperative Traffic

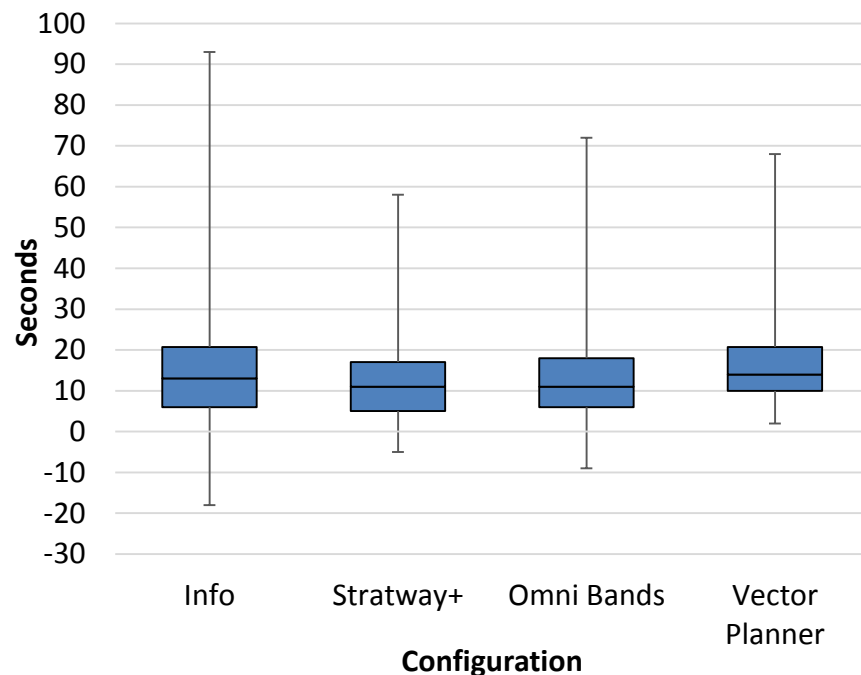
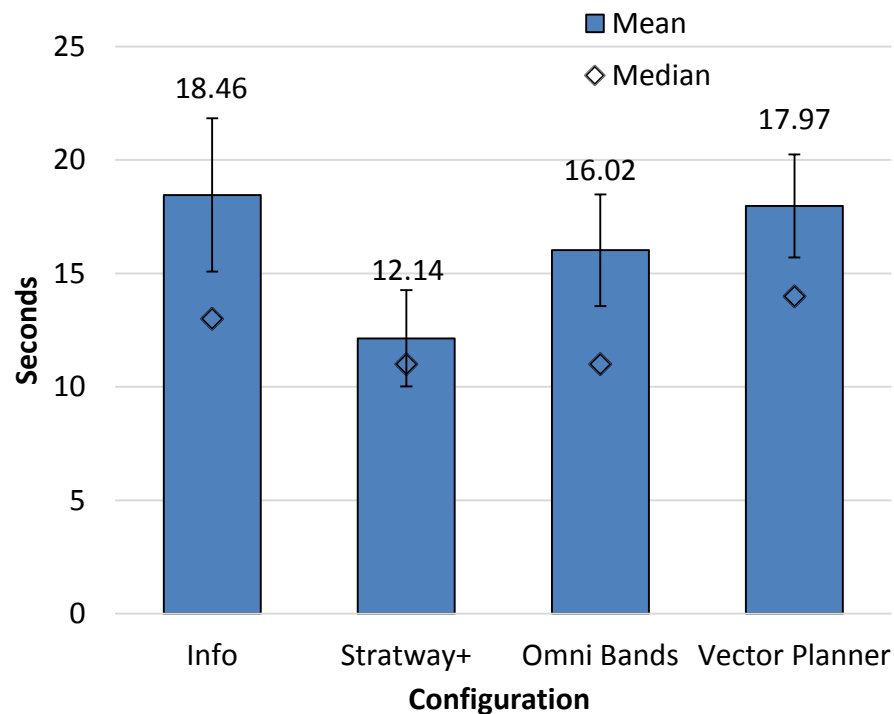


Measured Response Timeline & Associated Metrics

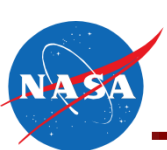




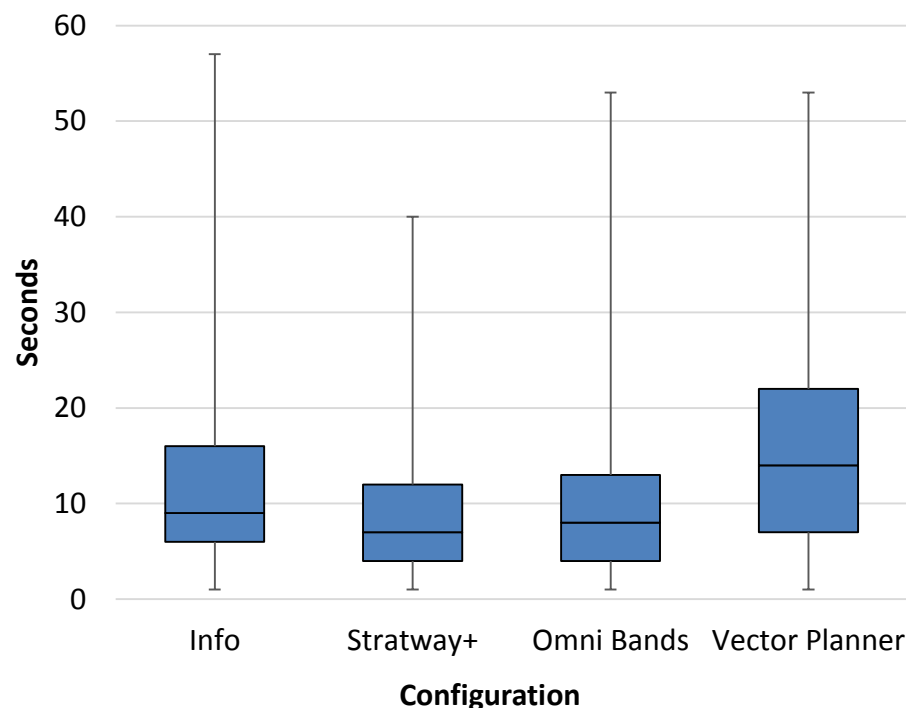
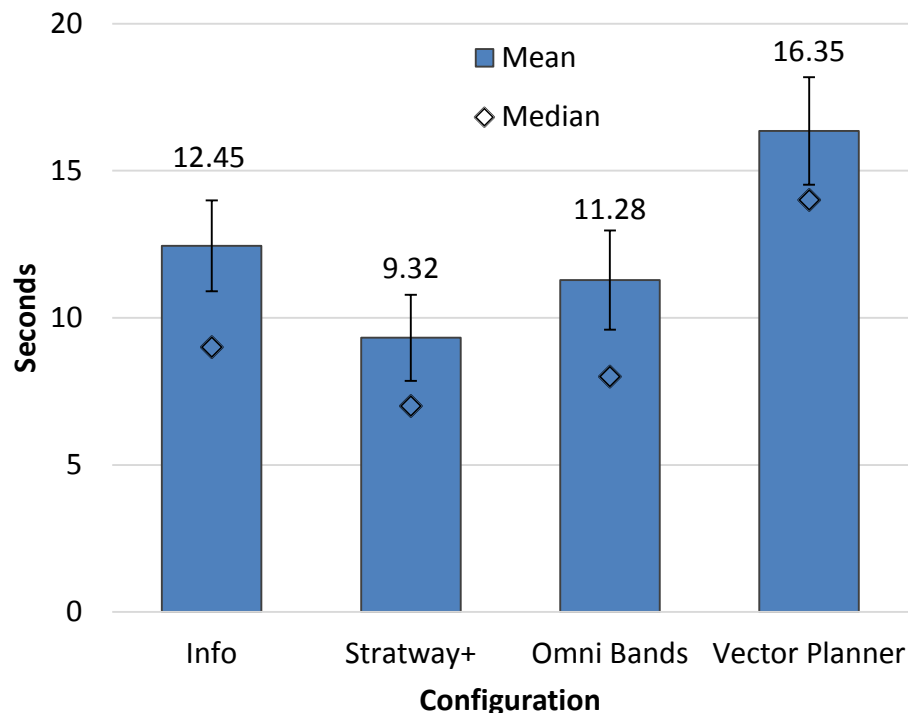
Notify Time



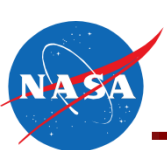
- There was no significant effect of Configuration on Notify Time for all SS alerts, $p > .05$
- On average, pilots took **16.15s** to notify ATC in response to a Corrective SS or SS Warning alert
 - 50% within 12s, 90% within 33s



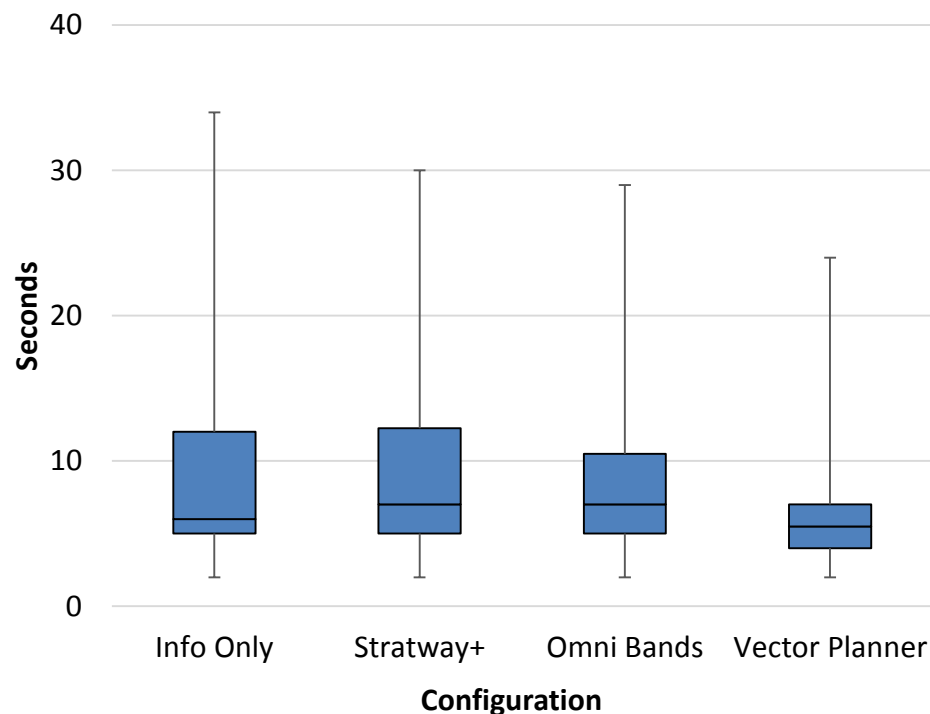
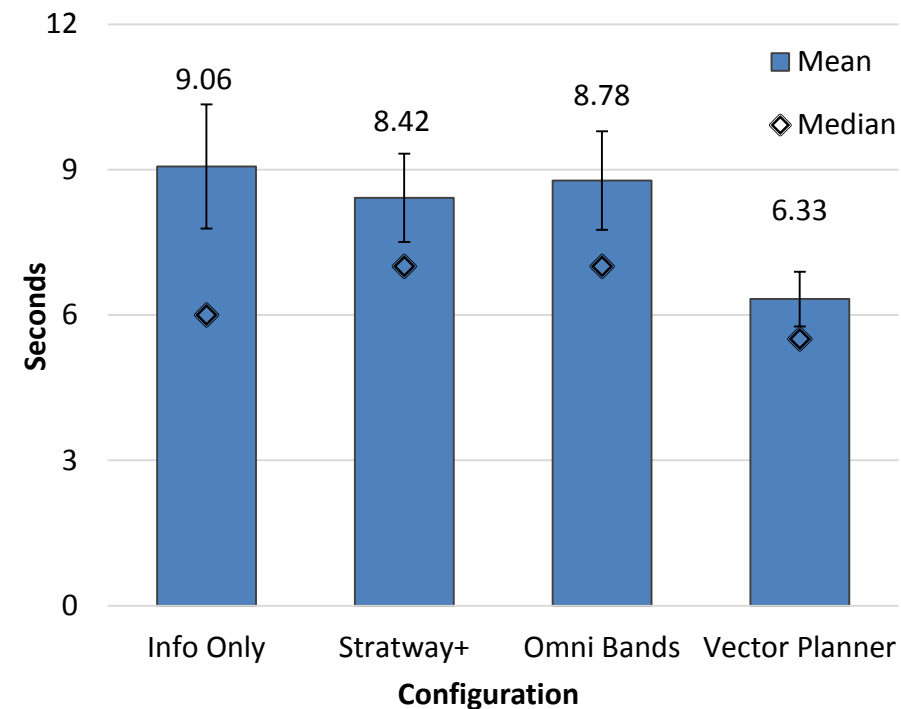
Initial Response Time



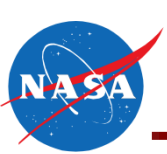
- Configuration had a significant effect on Initial RTs, $p < .01$:
 - Initial RTs for Stratway+ were **7.03s** shorter, on average, than those in Vector Planner, $p < 0.5$
 - Initial RTs for Omni Bands were **5.07s** shorter, on average, than those in Vector Planner, $p = .05$
 - No other configurations differed significantly
- On average, pilots took **12.35s** to initiate an edit in response to a Corrective SS or SS Warning alert
 - 50% within 12s, 90% within 36s



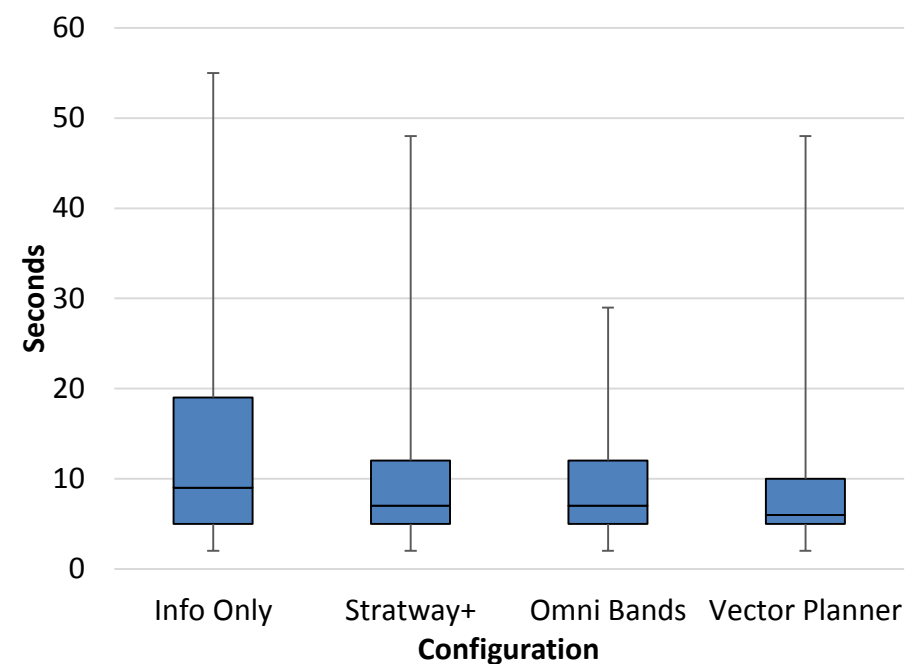
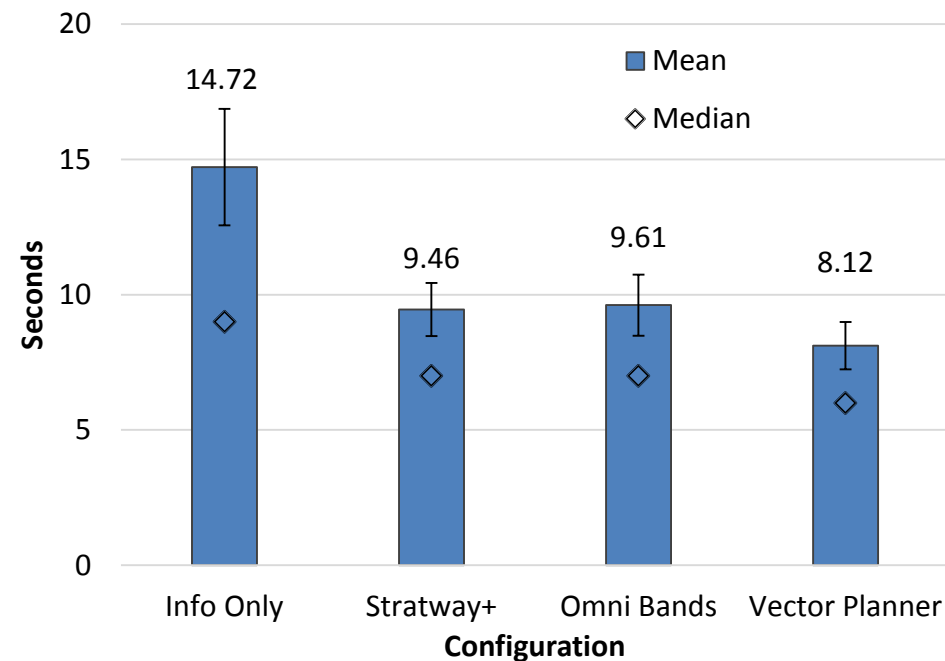
Initial Edit Time



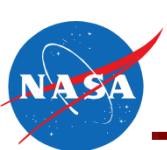
- No effect of configuration on initial edit times ($p > .05$)
- On average, pilots took **8s** to make an initial edit following a Corrective SS or SS Warning alert
 - 50% within 6s, 90% within 16s



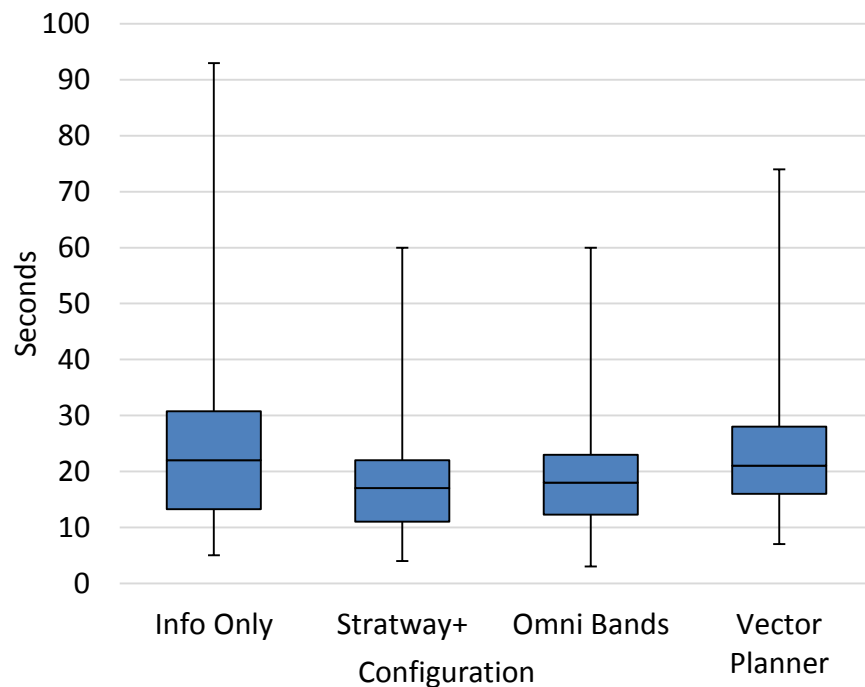
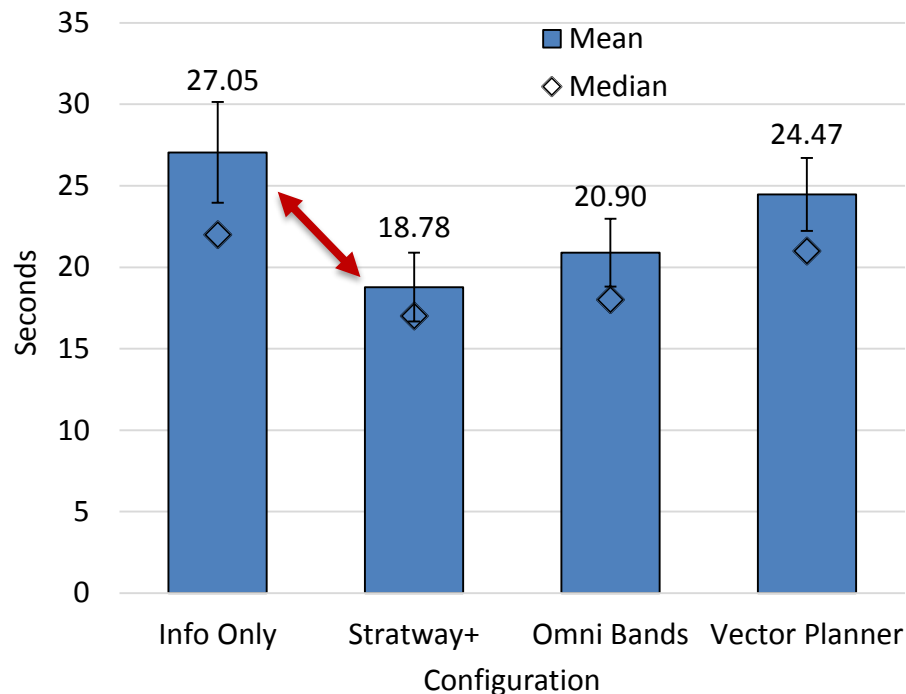
Total Edit Time



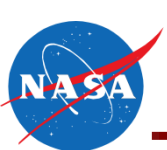
- Configuration had a significant effect on Total Edit times, $p < .05$:
 - Total Edit times for Vector Planner were **6.6s** shorter, on average, than those in Info Only, a significant difference, $p < 0.1$
 - No other configurations differed significantly
- On average, pilots took **10.7s** to upload their final maneuver after the initiation of an edit
 - 50% within 7s, 90% within 22s



Total Response Time

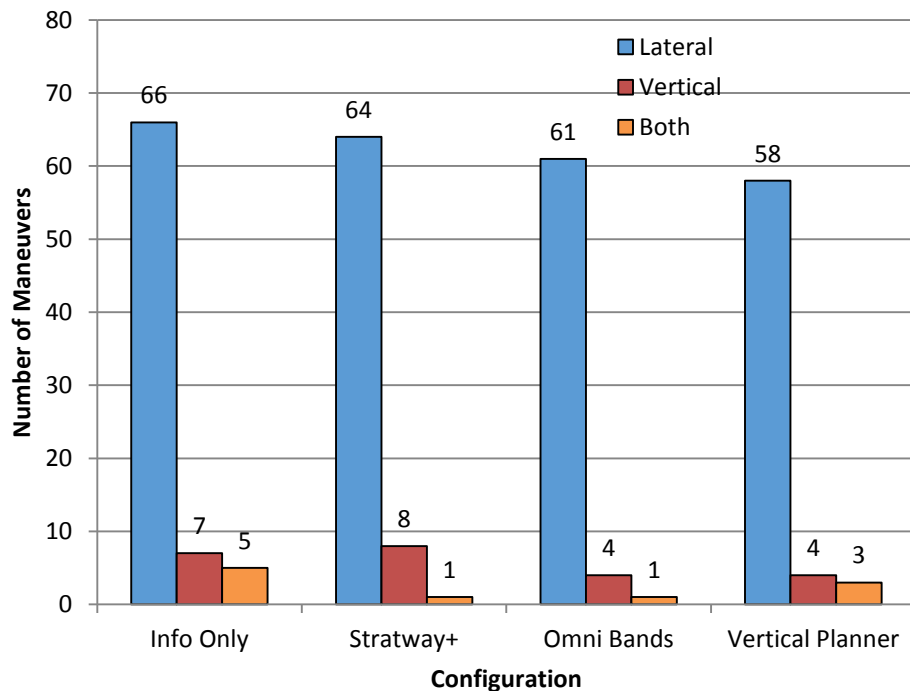


- Configuration had a significant effect on Total RTs:
 - Total RTs for Stratway+ were **8.2s** shorter, on average, than those in Info Only, a significant difference ($p=0.02$)
 - No other configurations differed significantly
- On average, pilots took **22.8s** to upload a final maneuver following the onset of a Corrective SS or SS Warning alert
 - 50% within 19s, 90% within 42s



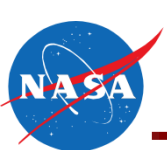
Maneuver Types

Maneuver Type by Display

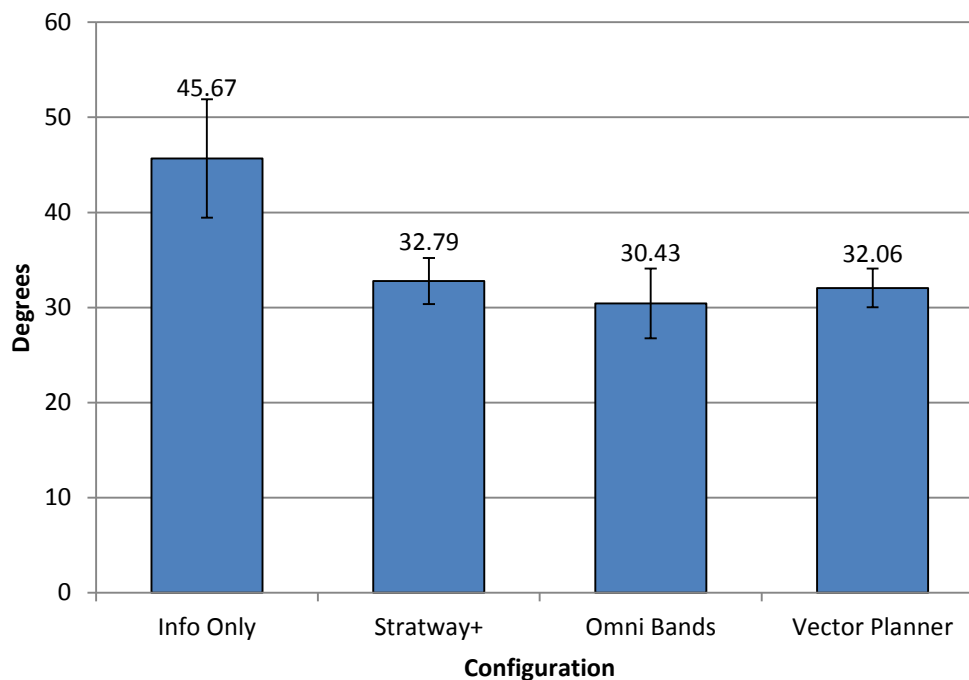


	Horizontal	Vertical	Both	Total
Info Only	66 (85%)	7 (9%)	5 (6%)	78
Stratway+	64 (88%)	8 (11%)	1 (1%)	73
Omni Bands	61 (92%)	4 (6%)	1 (2%)	66
Vector Planner	58 (89%)	4 (6%)	3 (5%)	65
Total	249 (88%)	23 (8%)	10 (4%)	282

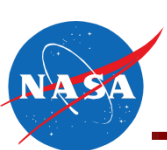
- Maneuver Type
 - 88% of maneuvers were in horizontal dimension
 - 8% of maneuvers were in vertical dimension
 - 4% of maneuvers were made in both dimensions



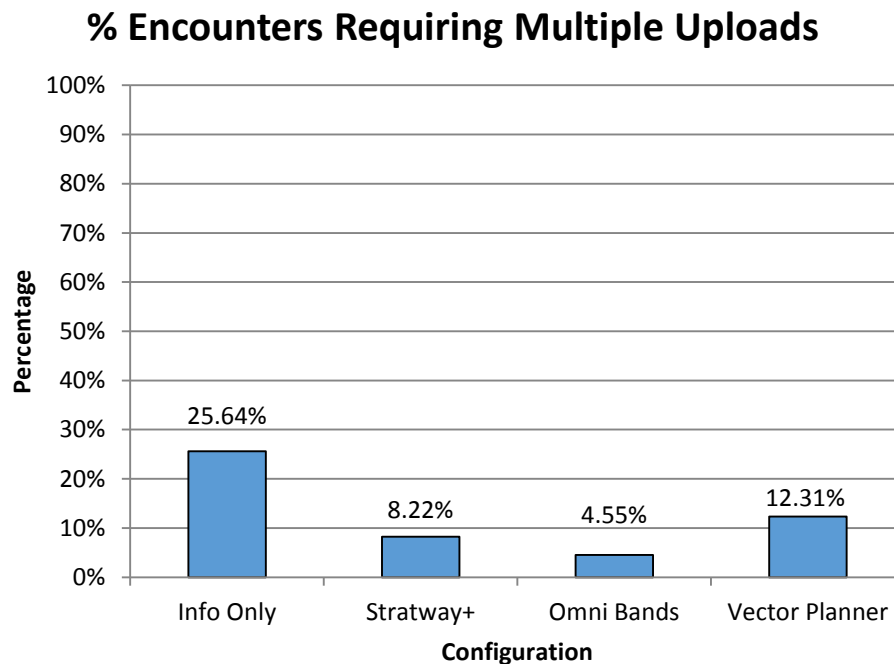
Horizontal Maneuver Size



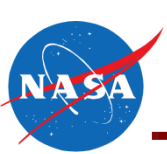
- Info Only resulted in horizontal maneuvers that were, on average, **10deg** larger than seen with the three guidance displays
 - Also see less variability between the three guidance displays
- Not enough data points to look at average vertical maneuver size



Number of Uploads

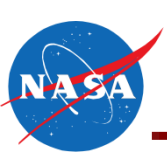


- Pilots required an average of **1.34** uploads per encounter in Info Only condition, compared to (roughly) 1.10 uploads per encounter with the remaining displays
 - **25%** of encounters in the Info Only display required more than 1 upload to maintain separation



Results Summary

- Notification Time & Initial Edit Time
 - No differences
- Initial Response Time
 - Vector Planning tools resulted in the slowest times, while remaining 3 displays were roughly equal
- Total Edit Time
 - Vector Planning tools resulted in fastest times, with banding displays slightly slower and Information Only the slowest
- Total Response Time
 - Fastest for Stratway+, but very close with Omni Bands
 - Vector Planning tools substantially slower, but Information Only far slower
- Maneuver Type
 - Overwhelming preference for lateral maneuvers, little variation between displays
- Maneuver Size
 - Larger lateral maneuvers for Information Only display, little difference between rest
- Encounters with Multiple Uploads
 - Least common with 2 banding displays
 - Vector planner roughly twice as likely, information only 4x as likely



Conclusion

- Suggestive maneuver guidance resulted in faster responses and more efficient maneuvers
 - The 2 banding displays (Stratway+ & Omni Bands) helped maintain consistently low interaction times – initial RT, initial & total edit
 - Vector Planner increased edit times but raised initial RT times
 - The 2 banding displays also minimized maneuver size and the number of multiple-upload maneuvers
 - Vector planner helped minimize maneuver sizes but led to twice the number of multiple-upload maneuvers than the banding displays